Implementing a Single Switch DC-DC Converter for Photo Voltaic System

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Abstract

This paper proposes a single switch non-isolated dc-dc converter for photovoltaic applications. The converter is created by buck converter amalgamation with a buck-boost converter. Such integration also resulted in decreased repeated power processing, thereby increasing the performance of conversions. With just a single transistor the converter is able to perform maximum power point tracking (MPPT), battery charging and load voltage control simultaneously. The MPPT and load voltage regulation is accomplished by regulating duty ratio and switching frequency of the switching pulse. The buck converter will work in discontinuous current conduction mode while the buck – boost converter will operate in continuous current conduction mode. The MPPT algorithm is an incremental conductance algorithm that provides satisfactory results on most conditions. The device must come out of incremental conductance algorithm to protect the battery from over loading and provides the battery with a steady charging voltage. The proposed system is evaluated under MATLAB SIMULINK and satisfactory results are obtained.

Keywords — *DC-DC power Converter, Incremental conductance algorithm, Maximum Power Point (MPP) Tracking (MPPT), Single Stage Single Switch Converter (SSC) and Variable Frequency Control.*

I. INTRODUCTION

Due to rising environmental issues such as increasing demand for electricity, the problems associated with fossil fuels have led to comprehensive research and development of renewable energy sources. One of those highly researched areas is the use of photovoltaic cells in energy production. The government has agreed in recent years to substainlly reduce the subsidies for photovoltaic systems [1]. PV systems are variable current source from which the transferred power depends on the solar arrays impedance in the output. The addition of a converter between PV system and output load is necessary. The normal power electronic converters are the most important components in terms of failure rate, service life and cost of maintenance Based on reliability studies, the failure rate of a DC-DC power converter is 41%. Semiconductor and soldering joints failures in power switches take up to 34% of power electronic system failures [2]. Hence the reduction of the number of switches is an efficient way to increase lifetime. For the maximum power point tracking (MPPT) of a PV array, charging/discharging the battery and to control the loads the conventional cascaded converter is used where buck converter cascaded with a buck-boost one [3] [4]. A high number of Power Switches indicates high converter cost and physical size. The repeated power processing decreases the efficiency of the system. To increase reliability and to decrease the cost and size of the PV systems a possible way is to form a single-stage converter from the cascaded one. Using a single switch for various current paths decreases the number of active switches like MOSFETs [5]. The single-switch (SSC) technology is well known in both the ac/dc and inverter domains. The authors in [6] suggested a three-phase single-stage power factor correction (PFC) interleaved converter for the ac/dc conversion. For the PFC ac/dc converter [7], a design based on the built-in buck-fly back technology [8] was applied. For the electrode less fluorescent lamps, single-stage high-power factor dimmable electronic ballast was introduced in [9]. A parallel-connected MPP tracking (MPPT) device is implemented to which the power loss due to repetitive power processing[10], which allows the input power to be transmitted directly to the battery and load due to the shunt link between the MPPT feature circuit and main power circuit. This solution eliminates the power loss but it takes two switches and associated MOSFET drive and control circuits. Meanwhile, the output voltage for the dc load is limited to the voltage of the PV input which limits the diversity of the load application.

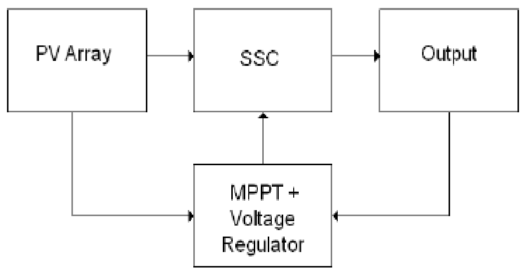

Fig.1: Block Diagram of Proposed Converter

In this paper a pulse-frequency modulation (PFM) control scheme is used to achieve the load controllability in a single-switch converter. In [11] it is proposed to improve the MPPT control algorithm by means of a centre point iteration approach with variable frequency perturbation. A power increment-aided incremental conductance MPPT approach is provided in [12], using variable-frequency / duty control. The authors in [13] proposed a method for shaping the input current for a better power factor in a single-stage ac / dc converter by changing the average switching frequency, whereas in [14] variable-frequency modulation is used to lower the voltage stress for rectifier regulators. This paper adopts the same principle of dual control but aims at different control variables, namely a variable-frequency control system is used for MPPT while standard duty cycle feedback control complies with the output regulation.

II. PROPOSED CONVERTER

The proposed single-stage photovoltaic system single switch converter is shown in the fig 2. It is derived from having a buck converter combined with a buck-boost converter.

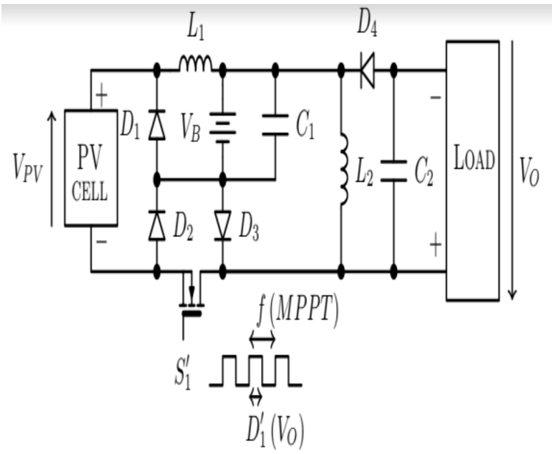

Fig.2: Proposed Converter Circuit Diagram

It consists of an inductor L1 that controls MPPT and charges the battery, a rechargeable battery VB to balance the input and output voltage, a capacitor C1 to absorb the battery's ac current ripple, an output inductor L2 to supply the load, a voltage switch S, four diodes (D1 to D4) and an output capacitor C2. Switch S provides current paths during the ON cycle for both the battery and the PV source, and also for reduced repeat power processing. Diodes D1 and D3 provide the current negative iB paths over various operating periods while diode D2 acts as a positive iB direction. Diode D4 binds the energy to the inductor L2 charge.

Mode 1

The switch S is ON at this point, the diodes D1, D3, and D4 are reverse biased, and the diode D2 is biased forwards. The PV source Vin loads up the input inductor L1.

The current through L2 is higher than current through L1.

iL2>iL1

The current through L2 is the sum of current through L1 and the battery discharging current.

iL2=iL1+iB

The mode ends when current through L1 become equal to current through L2.

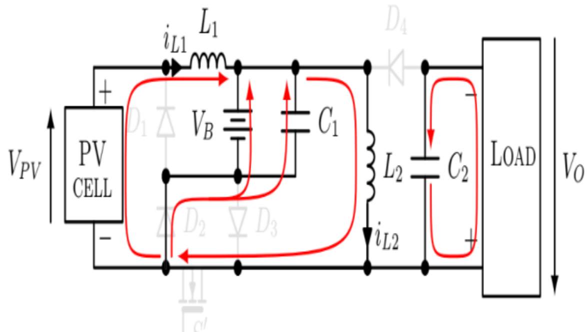

Fig.3: Proposed Converter Operation: Mode 1

Mode 2

In this mode when the inductor current iL1 is larger than iL2 when the switch S is ON. The extra energy from PV source Vin charges the battery and the capacitor C1, and hence, iB is reversed. Diode D3 provides the path for the negative iB while diode D2 is reverse biased. This mode terminates when the switch S gets turned off. At the end of this mode the current through L1 and L2 reaches its maximum level.

iL1>iL2

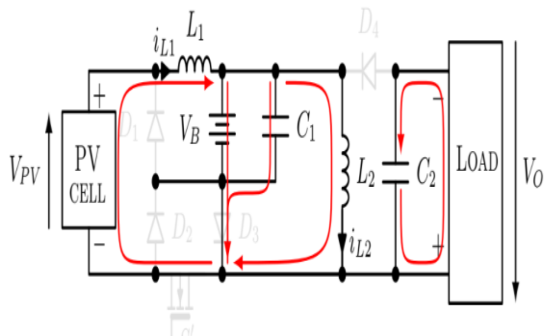

Fig.4: Proposed Converter Operation: Mode 2

The current through the L1 is the sum of the current through the L2 and the battery charging current.

iL1=iL2+iB

MODE 3

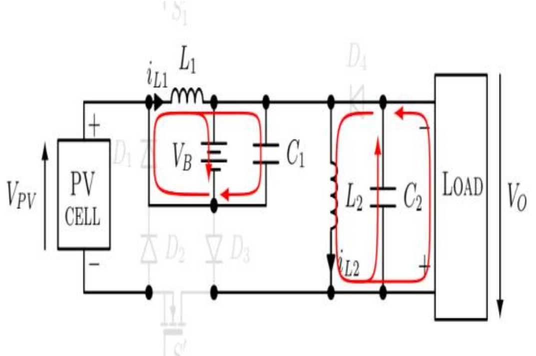

Fig.5: Proposed Converter Operation: Mode 3

This mode begins when switch S is switched off, the diodes D2 and D3 are reverse biased, and the inductor L1 discharges the stored energy through the diode D1 to the battery and capacitor C1. Inductor L2 begins releasing its stored energy to the output capacitor C2 and the load via diode D4 in the preceding stages.

MODE 4

Switch S is OFF during this period and input indutor L1 is reset. Inductor L2 continues to discharge its stored energy via the diode D4 to the output capacitor C2 and the pump load until the next switching period.

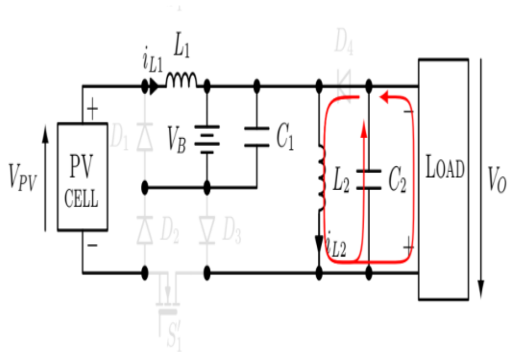

Fig.6: Proposed Converter Operation: Mode 4

III. MPPT AND VOLTAGE CONTROL

To obtain the full power from the PV array, an incremental conductance algorithm is used. For the MPPT algorithm the current and voltage of the PV array must be calculated simultaneously. The operating voltage of the PV array is controlled through variable frequency control. It is achieved due to the discontinuous current conduction of the inductor L1. The flow chart for the algorithm is given in figure. The output to input gain (M) of the buck converter which constitutes the front end of the SSC under discontinuous conduction mode (DCM) is given by

$$M = \frac{Vb}{Vin} = \frac{2}{1+\sqrt{1+\frac{8L1f}{D^2R}}}$$

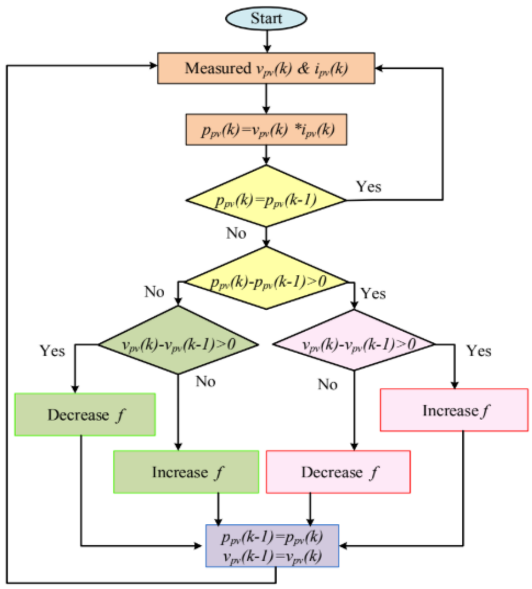

Fig.7: Flowchart for Incremental Conductance Algorithm

Where, D is the duty ratio of the switching pulse to the switch, f is the switching frequency, and R is the equivalent resistance of the battery which is a unknown quantity

Assuming the loss less system, the output power and input power are equal. Then R can be calculated approximately as

$$R=\frac{Vb^2}{Vin\ Iin}$$

The product of Vin and Iin gives the input power. Rearranging the terms, it can be derived that

$$\frac{Vin}{Iin}-\frac{Vb}{Iin}=\frac{2L1f}{D^{\wedge}2}$$

The MPPT can be achieved using either variable frequency control or duty cycle control. Since precise output voltage regulation is needed, MPPT is achieved with variable frequency control. It is because the duty cycle control shows larger control range than variable frequency control. The output voltage regulation achieved by duty cycle control. The buck-boost inductor operates in continuous conduction mode (CCM), hence the gain 'K' of the converter is given by

$$K=\frac{Vo}{Vb}=\frac{-D}{1-D}$$

IV. SIMULATION

The simulation model of SCC for PV-battery system is developed in the MATLAB SIMULINK. For the simulation, the switching frequency is limited to run between 2 KHz to 120 KHz and MOSFET is used as the switching device. For the PI controller kp and Ki is chosen as .02 and 3 respectively. The load is purely resistive and its value is taken as 50 Ω. Fig shows the current through the inductor L1. Since it is selected as to work under DCM, the current is zero for some time in one cycle. It has peak current of 2A at the peak.

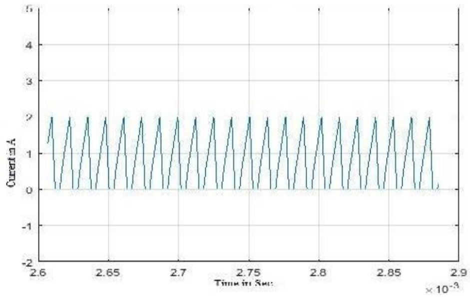

Fig.8: Current through Inductor L1

The fig shows the current through inductor L2 and it is working under CCM.

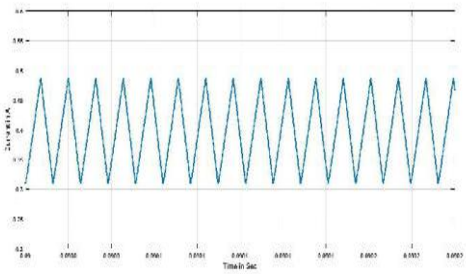

Fig.9: Current through Inductor L2

Fig shows the output voltage of single switch converter. The reference value set as -14 V and it takes 0.04 seconds to reach the desired value which effects the starting of MPPT algorithm. The output voltage has a negative polarity due to the buck-boost topology.

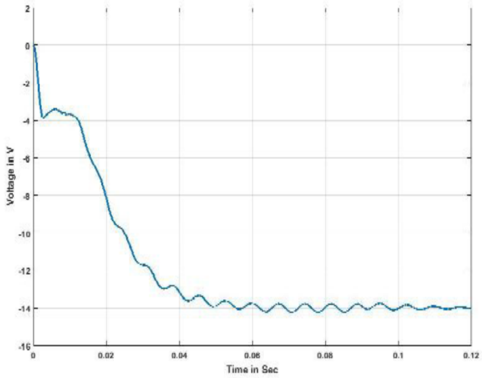

Fig.10: Output Voltage of Proposed Converter

V. CONCLUSION

To increase reliability and decrease the overall cost of a PV-battery-load power system, a Single-Switch DC-DC Converter (SSC) instead of a two stage conventional one, is proposed. A single switch converter for a PV battery system performing Maximum power point tracking, output voltage regulation, and battery charging is presented in this chapter. The incremental conductance algorithm is used in this paper. The MPPT is achieved using variable frequency control whereas the output voltage regulation is done by duty cycle control. But due to the high voltage stress problem, it can only be used for low to medium power applications.

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